# Comparison of Reinforcement Benefits of Spray-on Linings in Side-by-Side Unconfined Compression Failure Tests on Rock

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## ABSTRACT

Testing has been accomplished to substantiate recent laboratory trials which have demonstrated that thin liner membranes, applied to rock core samples, can significantly enhance the structural performance of such rock materials. A range of Canadian polymer liner materials (Mineguard™, Rockguard™ and RockWeb™) have been tested side-by-side to evaluate strength and other physical property improvements generated for two highly homogeneous, though differently sourced, granodioritic rock materials. Tests were conducted on physically similar core materials, utilizing 104 to 113 samples of each respective rock type. For both rock sample populations, cores were coated using linings at thicknesses varying between 1 and 7.3 mm, typical of the application range currently used underground by mines contemplating use of such membrane agents. Results of rock failure tests, following application of passive lining covers upon the very large sample populations of each rock type, have indicated that noticeable strength improvement and enhancement of post-yield failure characteristics can be developed by the entire range of spray-on liner materials evaluated. It is shown that all of the tested liner agent materials currently available can and do act to positively reinforce rock support capabilities of modeled core pillars. Where liner materials can be effectively placed underground, it is anticipated that they may provide similar benefit and be successfully used in partial replacement for either screen or shotcrete to provide advantageous area support for rock.

## INTRODUCTION

To bridge perceived gaps in support capabilities existing between current forms of mine area support and to enhance future capabilities for high speed development in deep mining environments, spray-on polymeric area support materials have been introduced and are undergoing extensive review. A wide variety of materials have been developed, including polyurethane-based Mineguard™, polyurethane/polyurea-based Rockguard™, polyurea-based RockWeb™, methacrylate-based Superskin®, latex-based Tekflex™, and acrylic-based Evermine (Archibald et al. 1997(a), 1997(b), 2000(a)), (Espley et al., 1999), (Spray-on Plastics, 2000), (Futura, 1998). Several of these products, notably Mineguard™, Rockguard™, RockWeb™ and Tekflex™, are manufactured in Canada and have undergone considerable long term, qualitative assessment by various Canadian mining organizations. Other products, only because of their more recent development (Superskin®) or very limited international use (Evermine), have undergone less Canadian testing, and are thus not currently as well recognized within the mining industry. As more development and testing occurs, however, it is expected that these and newer products will gain significant recognition by the mining industry for their capacities to provide substantial area support benefit while reducing traditional high costs to provide such support. Much work has been performed to date to assess the physical properties of these lining materials (Archibald et al., 1999), (Tannant et al., 1999), using a variety of different test techniques. A brief listing of product sourcing and physical characteristics for several of the better known and more commonly utilized spray-on liner materials is provided in Table 1. Existing and future work is, however, being directed towards establishing universal acceptance standards for the broad range of these novel materials, particularly within the Province of Ontario. Research investigation is being funded, for example, by the Workplace Safety and Insurance Board of Ontario (WSIB), under the sponsorship of the Mines and Aggregates Safety and Association (MASHA), to perfect standardized test procedures which will permit quantification of various physical characteristics of lining materials (WSIB, 2000). These test procedures will be developed to permit assessment of liner support performance capabilities, and any potential health and safety hazards associated with conditions such as flame exposure, gas inflow, water inflow, loose retention, dynamic rock movement and possibly rockbursting.

**Table 1. Comparison of Physical Attributes of Spray-On Area Support Coatings**

| Feature | Mineguard™ | Rockguard™ | RockWeb™ | Superskin® | TekFlex™ |
|---|---|---|---|---|---|
| Source | Mineguard Canada<br>101 Holiday Inn Dr.<br>Unit 210B<br>Cambridge, ON<br>N3C 1Z3<br>(519)-249-0580 | Engineered Coatings<br>Regn'l Rd. 22<br>Unit A<br>Cambridge, ON<br>N1R 5S3<br>(519)-622-8811 | Spray-On Plastics<br>Side Road 20<br>RR #5<br>Rockwood, ON<br>N0B 2K0<br>(519)-837-0374 | Master Builders<br>23700 Chagrin Blvd.<br>Cleveland, OH<br>44122-5554<br>(216)-831-5500 | Fosroc Inc.<br>150 Carley Court<br>Georgetown, KY<br>40324<br>(502)-868-6219 |
| Mix Type: | liquid/liquid<br>(polyurethane) | liquid/liquid<br>(hybrid polyurea/ polyurethane) | liquid/liquid<br>(polyurea) | liquid/liquid<br>(methacrylate) | liquid/powder<br>(latex-based) |
| Tensile Strength (MPa): | 10 - 18<br>(@ 1 hour) | 14 - 16<br>(@ 1 hour) | 18.5<br>(@ 1 hour) | > 2.0<br>(@ 1 hour) | > 1.0<br>(@ 8 hours) &<br>3.0 @ 28 days |
| Set Time: | 10 seconds | 10 seconds | 10 seconds | < 3 minutes | N/A |
| 90-95% Cure Time: | 10 minutes | 10 minutes | 10 minutes | | N/A |

Observed and measured support capabilities

Previous rock support trials have been conducted at mine and laboratory sites to determine the reinforcement potential of liners, and to assess their effectiveness relative to existing standard support techniques. This work reviewed both laboratory simulations of loose rock deformations and in-situ observation of falls of loose, constrained solely by polymeric layer strength and rock adhesion (see Figure 1). Although originally intended only to act as a partial replacement for the screen component of bolt-and-screen support, some liner agents have been observed to be capable of achieving significant area support resistance on their own, and to act as a potential replacement for shotcrete in certain underground support situations. Such support capacity is illustrated in the mine photograph, in which a 2 mm thick layer of Mineguard™ was observed to suspend a volume of broken rock (0.5 m x 0.5m x 0.5m in size) from a drift back. The various forms of polymeric linings (Mineguard™, Rockguard™ and RockWeb™) have demonstrated capabilities to achieve area support resistance which lies intermediate between that which can be generated by bolt-and-screen and shotcrete media. Spray-on liner materials, of all types, have also demonstrated capabilities to be installed at exceptionally high rates, to cure within minutes of application and to exhibit significantly beneficial production and handling advantages over both other forms of traditional area support methods (Archibald et al. 1997(b)). Additional review has determined that the use of spray-on liners offers considerable merit for applications requiring short-term ground support as a means of speeding up conventional development processes (Espley-Boudreau, 1999), (Archibald et al., 2000(b)). This consensus derives from the potential of spray-on linings to realize increased support cycle efficiencies, increased development and productivity rates, compression of mining cycle times and enhancement of mine safety through reduction in support installation injuries.

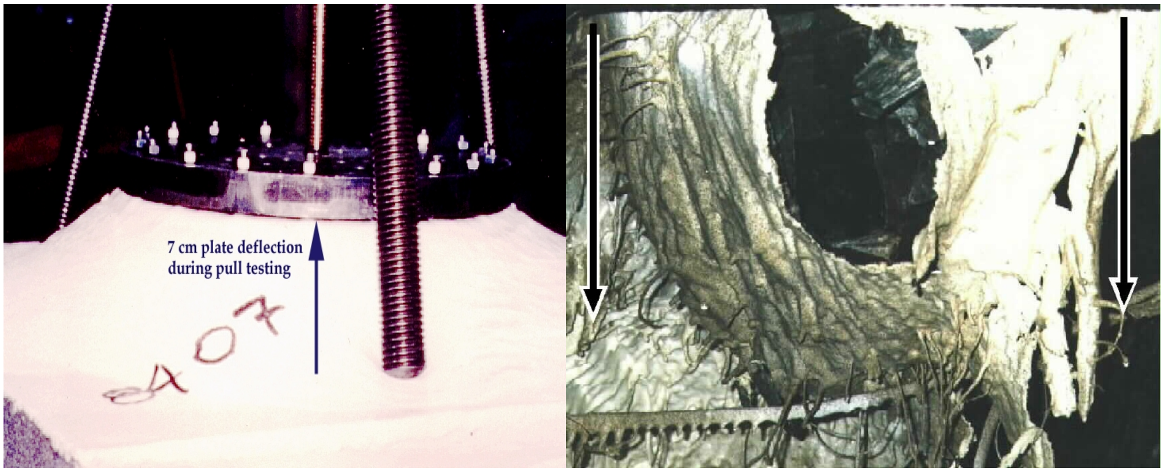
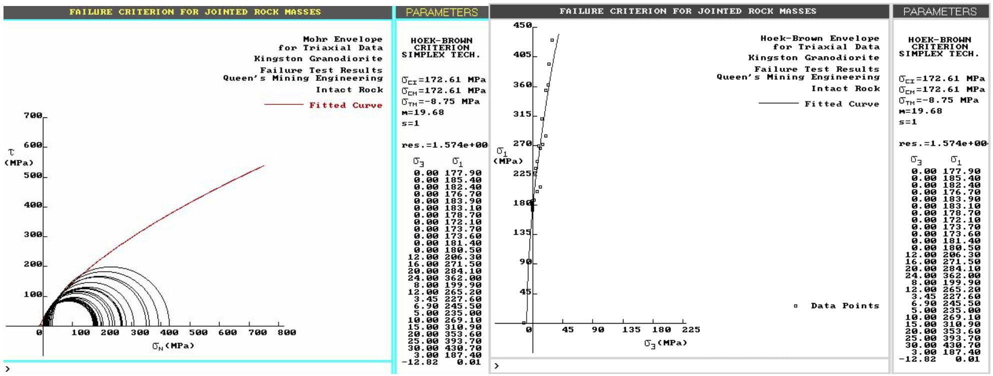



**Figure 1. Laboratory pull testing and in-situ loose block restraint provided by Mineguard™**

## ASSESSMENT OF ROCK REINFORCEMENT POTENTIAL

Recent laboratory testing established that spray-on lining materials can offer significant reinforcement potential in controlling pre- and post-yield rock failure of simulated rock pillar structures (Archibald et al., 2000). Prior to these tests, the majority of laboratory pillar failure model studies were conducted using only single rock types and polymer coating agents. No side-by-side assessment of support benefits for various liner types, even using single and highly homogeneous rock material, had ever been examined. A series of initial tests were therefore initiated to assess reinforcement capability variation of a range of passive liner materials following their application onto one homogeneous rock material. Polymeric materials tested were Mineguard™, Rockguard™ and RockWeb™, and the initial rock material, from which test core specimens were manufactured, consisted of Kingston granodiorite. This rock, characterized as a coarse-grained granodiorite with a quartz/mica mineral inclusion ratio approximating 1:1, was selected for its homogeneity in physical composition and strength. Samples, retrieved from the Queen's Explosives Test Site, located near Hinchinbrooke, Ontario, were found to be generally intact, though possibly microfractured due to constant exposure to ground vibrations and impact damage from flyrock. In this first series of test trials, a wide range of failure tests were conducted. Analysis included completion of fully unconfined (uncoated), passively-confined (polymer-coated) and triaxial-confined failure tests of cores which were subjected to axial strains in excess of 3%. The sum of all unconfined and triaxial-confined failure data was utilized to derive the inherent strength parameters for this Kingston granodiorite material, according to both Mohr-Coulomb and Hoek-Brown failure formats (see Figure 2).

Through use of specialized compression testing frames, some limited measure of post-yield failure was able to be achieved for all samples tested. Tests were, however, performed at loading rates sufficiently high to insure that controllable, post-yield failure progression could not be achieved when samples were left fully unconfined. This process was implemented to force propagation of catastrophic failure conditions (similar to rockbursting) in fully unconfined samples following achievement of yield and limited post-yield strength conditions. Under such conditions, unconfined core sample failures occurred through development of axial and shear fractures, with violence. Polymer-coated samples, while demonstrating similar shear and axial fracture development, exhibited significantly less severe damage response and easily controllable failure progression. Where passive spray-on coatings were applied, controlled and significant post-yield failure progression was systematically achieved in all core sample tests.




| Mohr-Coulomb Linear Regression Parameters | Hoek-Brown Simplex Analysis Parameters |
|---|---|
| $\sigma_C$ = 174.4 MPa | $\sigma_C$ = 172.6 MPa |
| Cohesion = 30.4 MPa | $\sigma_T$ = 8.75 MPa |
| $\phi$ = 51.6$^0$ | m = 19.7 |
| Failure Angle = 70.8$^0$ | s = 1 |
| Correlation Coefficient = 0.914 | Correlation Coefficient = 0.873 |

**Figure 2. Characteristic Kingston granodiorite failure envelopes and mechanical properties**

<u>Test procedures - initial phase for Kingston granodiorite</u>

A total of 104 NX core specimens (5.08 mm diameter) were drilled from intact Kingston granodiorite blocks which were recovered following surface blasting at a local Kingston test site. Unconfined and triaxial-confined sample test data for twenty-nine samples was used to generate plots of axial force and deformation response, from which estimates of pertinent rock strength and energy storage characteristics of the granodiorite material were derived. Three additional series of passive unconfined failure tests were also conducted in which groups of between twenty and thirty-five granodiorite core samples were each coated using various thicknesses of the three available spray-on lining materials. Thicknesses of each polymer material, ranging between 1 and 5.5 mm, were applied to all sample core populations. Upon initiation of these failure tests, no active confinement was expected to be generated by the emplaced liners which could offer strength enhancement to specimens. Coated core failure tests were conducted under conditions of loading identical to those set for unconfined and triaxial-confined tests in the initial characterization phase. Core specimen failure was carried through pre- and post-yield loading, with maximum axial displacements of 4 mm being permitted. For average specimen lengths approximating 120 mm, axial strains equivalent to 3.33% were achieved for all coated Kingston granodiorite samples. From generated load/deformation data, a range of characteristic parameters were derived for each sample test, whether unconfined or passively confined using polymer liner agents (see Figure 3).

The peak and residual strength parameters represent the maximum and long-term (or post-yield) strength conditions measured. The post-yield region defines a region of progressive core failure through which sample confinement was generated following polymer liner installation, and failing rock material was able to maintain demonstrable load resistance or support capacity relative to unconfined materials. For the Kingston granodiorite tests, the residual strengths were arbitrarily measured after 4 mm of axial displacement had occurred. The pre-yield energy storage capacity (in Joules) represents that area lying beneath the load/deformation curve within the pre-yield portion of the failure cycle. The post-yield energy storage capacity represents that area lying below the limiting force/deformation curve between the peak and final (or residual) load state which existed after 4.0 mm of sample axial deformation had taken place. To calculate stored energy capacities, areas beneath the load/deformation curves were subjected to Simpson's Rule determination according to a proprietary program which was developed by Nicholls and Everets (1999). Parametric data was compiled versus individual layer material thickness applied to assess trends in initial strength and post-yield failure behaviour that developed during these tests.

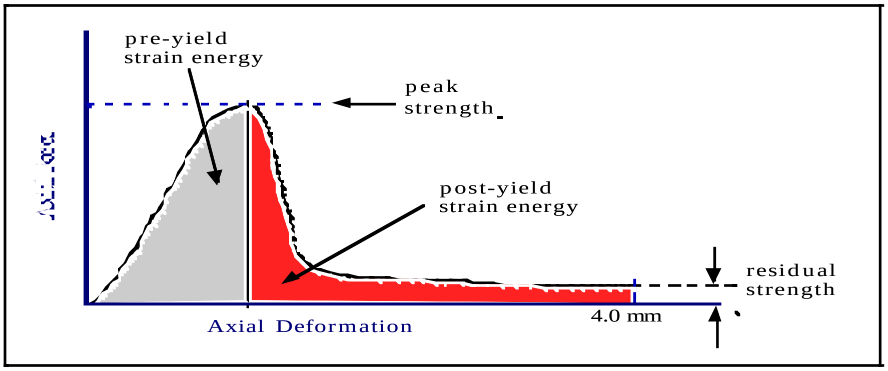
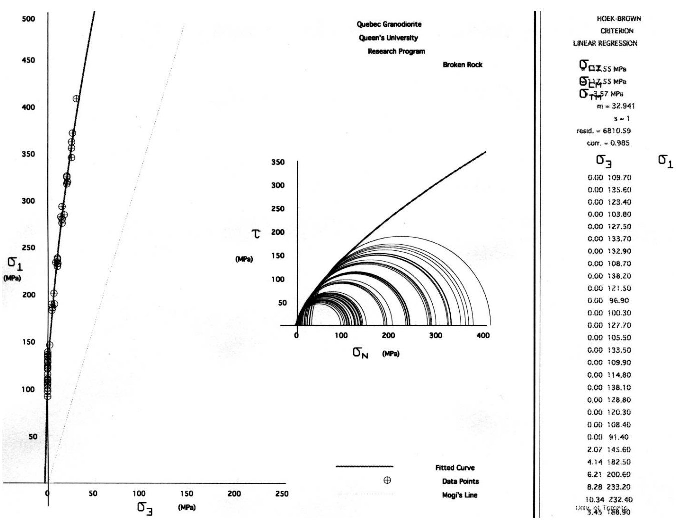



**Figure 3. Typical force-deformation plots for polymer-coated core specimen failure tests sh**

Test procedures - second phase for Quebec granodiorite

A second suite of 113 NX core specimens were manufactured from intact Quebec granodiorite blocks. This Quebec material, a coarse-grained granodiorite, evidenced a quartz/mica mineral inclusion ratio approximating 2:1, and was obtained from surface-quarrying, rather than blasting, as had been the case for Kingston granodiorite materials. For this reason, the Quebec granodiorite material was expected to be significantly less influenced by surficial fractures, as may have occurred for the Kingston granodiorite material during blast excavation. Unconfined and triaxial-confined tests were conducted upon thirty-seven of these samples and used to derive the inherent strength parameters for this Quebec granodiorite material, according to both Mohr-Coulomb and Hoek-Brown failure formats (see Figure 4).




| Mohr-Coulomb Linear Regression Parameters | Hoek-Brown Simplex Analysis Parameters |
| --- | --- |
| $\sigma_C$ = 118.7 MPa | $\sigma_C$ = 118.7 MPa |
| Cohesion = 20.3 MPa | $\sigma_T$ = 7.72 MPa |
| $\phi$ = $54.4^0$ | m = 32.48 |
| Failure Angle = $65.1^0$ | s = 1 |
| Correlation Coefficient = 0.977 | Correlation Coefficient = 0.985 |

**Figure 4. Characteristic Quebec granodiorite failure envelopes and mechanical properties**

The results of characterization tests indicated that the Quebec granodiorite material exhibited dissimilar strength behaviour relative to the Kingston granodiorite material, but yielded strengths which were also uniformly homogeneous over the entire range of specimens tested. The Quebec granodiorite was shown to have approximately 35% weaker unconfined compression and cohesion strength properties, but also exhibited approximately similar tensile strength character.

Three additional series of passive unconfined failure tests were also conducted on this second rock material in which groups of between nineteen and thirty-four core samples were each coated using various thicknesses of the three selected spray-on lining materials. Thicknesses of each polymer material, ranging between 1 and 7.3 mm, were applied to all sample core populations of Quebec granodiorite. Coated core failure tests were conducted under conditions of loading identical to those set for unconfined and triaxial-confined tests in the initial characterization phase. In these tests, however, core specimen failure was carried through pre- and post-yield loading, with maximum axial displacements of 10 mm being permitted. For average specimen lengths approximating 120 mm, axial strains equivalent to 8.33% were achieved for all coated Quebec granodiorite samples. The post-yield energy storage capacity which was generated for the Quebec granodiorite tests represented that area lying below the limiting force/deformation curve between the peak and final (or residual) load state which existed after 10 mm of sample axial deformation had taken place. Parametric data was compiled versus individual layer material thickness applied to assess trends in initial strength and post-yield failure behaviour that developed during these tests.

## Results for Kingston and Quebec granodiorite spray-coated core specimen tests

Data shown in Figures 2 and 4 illustrate that well defined triaxial and unconfined compressive strength (UCS) parameters can be defined for each granodiorite material selected. Based solely upon measured unconfined strength data, the average UCS for these materials approximates 179.1 MPa and 118.7 MPa, for Kingston and Quebec granodiorite, respectively. Plots of axial force and deformation response, for uncoated and coated specimens in both granodiorite test series, illustrated that definite strength and energy storage enhancement can develop following sample coverage by polymeric materials (Figure 5). In both series of sample tests, where core samples were tested totally unconfined, some limited measure of post-yield failure was able to be achieved. In the typical sample plots shown, peak strength was first exceeded and a gradual loss of loading capacity was developed in conjunction with growth of progressive axial and shear fracture webs throughout the tested specimens. Due to the rates of loading applied, unconfined failure was also forced to develop in a rapid and often catastrophic fashion. Such core specimens were induced to fail violently, resulting in an inability to sustain any residual support or strain energy storage capacity past the initial portion of post-yield failure. However, where these same core samples were coated using the variety of spray-on polymer lining materials, significant peak and residual strength improvement, as well as a capacity to extend controlled, yielding failure well into post-yield, was evident. As illustrated in the typical force/deformation plots of Figure 5, all coated samples were shown capable of sustaining considerable and stable post-yield load support over very large deformation ranges. In addition to sustaining residual strengths that were appreciable fractions of rock material peak strength conditions, no violent failure phenomena were observed in any of the coated core tests. When strength data for all tests was compiled, achieved by combining results for tests conducted using all three polymeric liner agents for each rock material used, it was indicated that strong, positive trends in strength and energy storage capacity improvement can develop as lining thicknesses applied increase (Figures 6 and 7). On the basis of information obtained from the characteristic failure curves for coated rock core specimens, strength trends also evidenced dissimilarity between the various liner agent materials utilized. This is further illustrated in the plotted data of Figures 8 and 9. In these plots, very similar residual strength enhancement versus liner thickness applied was shown to be developed for all liner agents used. Notable differences in strength enhancement were, however, shown to be developed between liner agent materials in terms of peak strength capacity. Summary strength and energy storage capacity versus liner thickness trend conditions, seen for both rock types and all liner agents used, are listed in Table 2 and substantiate these conclusions. Due to differences in spraying sources, similar coating thickness ranges were unable to be achieved for all polymeric linings, and a wide range in layer thickness was noted to exist between liner types studied. Additionally, thicknesses ranging between approximately 1 and 5.5 mm were achieved for initial Kingston granodiorite tests, and between approximately 1 and 7.5 mm for subsequent Quebec granodiorite tests.

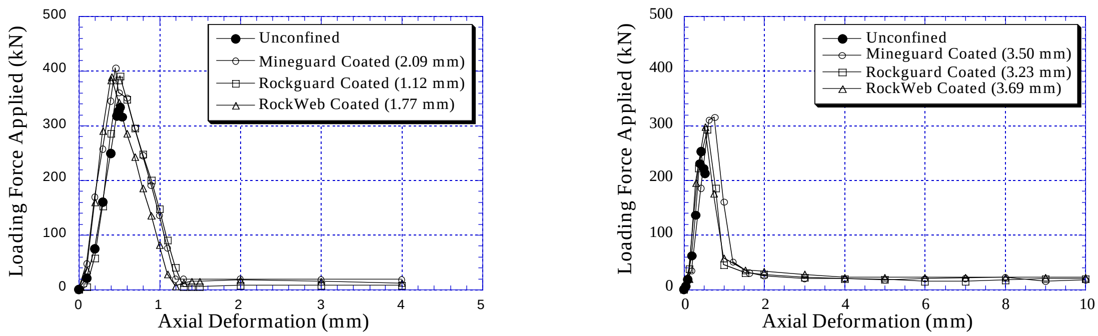



**Figure 5. Plotted force/deformation data for typical Kingston and Quebec granodiorite core specimens, tested both unconfined and with passive liner coatings applied**

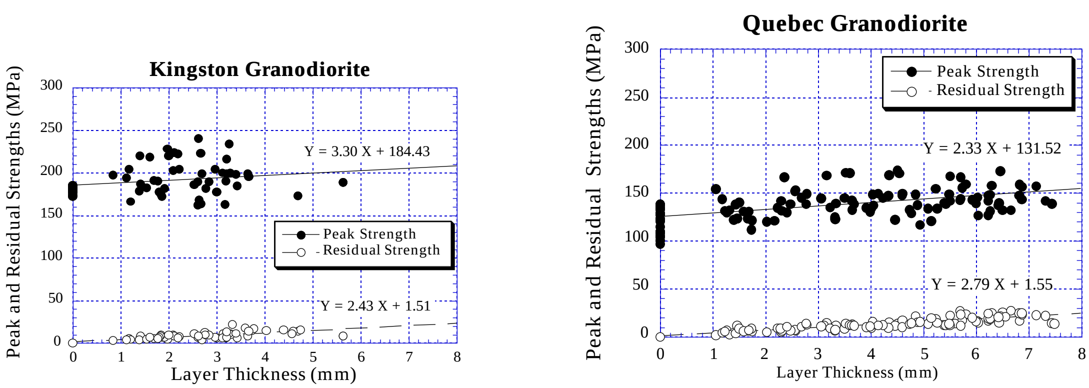



**Figure 6. Combined peak and residual strength data for Kingston and Quebec granodiorite cores when coated using Mineguard™, Rockguard™ and RockWeb™ linings**

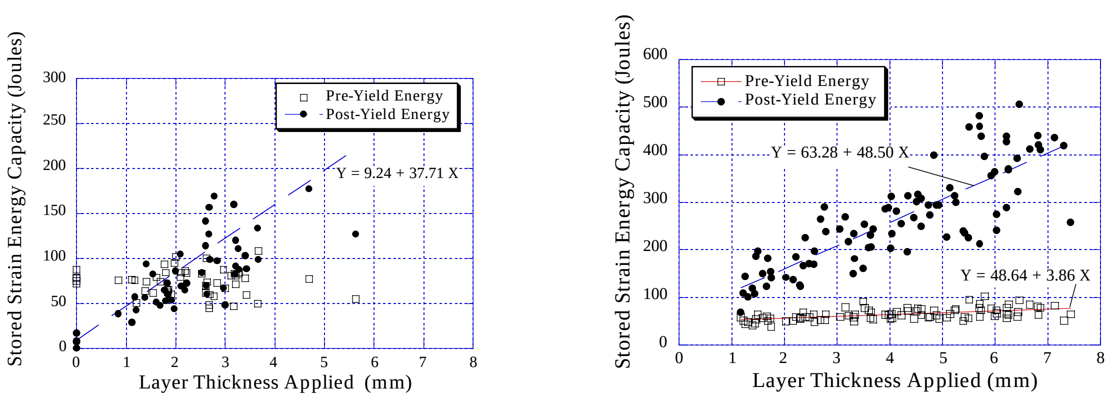



**Figure 7. Combined pre- and post-yield strain energy storage capacities for Kingston and Quebec granodiorite cores (data summed for all liner material tests)**

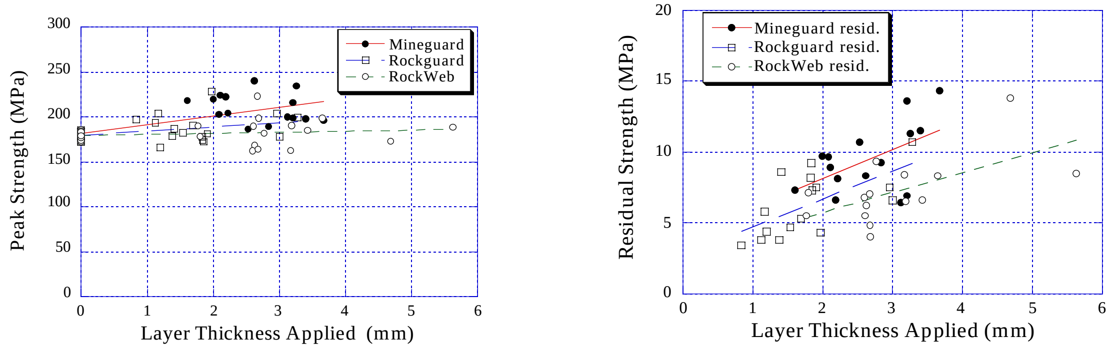



**Figure 8. Peak and residual strength capacity versus liner thickness trends for individual liner materials applied to Kingston granodiorite rock test specimens**

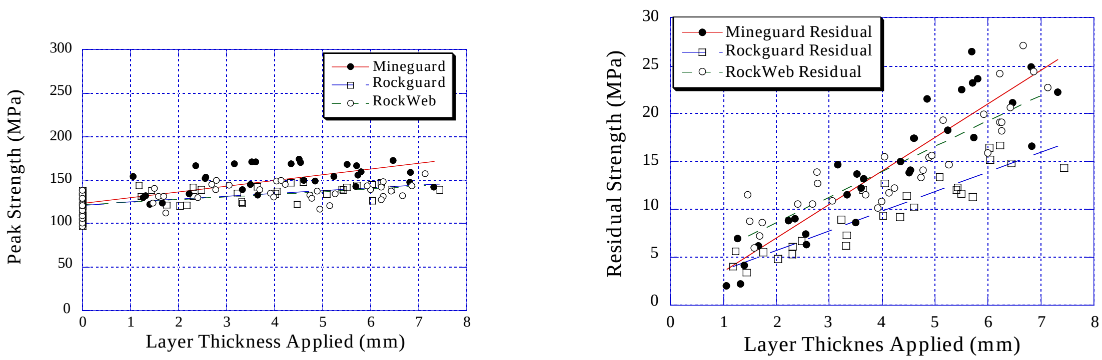



**Figure 9. Peak and residual strength capacity versus liner thickness trends for individual liner materials applied to Quebec granodiorite rock test specimens**

Due to an inability to install uniform ranges of lining thickness for all three coating materials used, some variation in rock characteristic enhancement between coating systems was therefore expected, and realized (see Table 2). However, positive peak and residual strength benefits were demonstrated for all lining materials when used on both types of rock, with some benefit variation being indicated. For the Kingston granodiorite material tests, peak strength enhancement was shown to range between 1.2 MPa/mm of lining thickness applied (for RockWeb™) to as much as 9.6 MPa/mm of lining thickness applied (for Mineguard™). Residual strength enhancement for this same rock material, though lower in magnitude, evidenced a range of between 1.4 MPa/mm of liner (for RockWeb™) and 2.1 MPa/mm of liner (for Mineguard™). In determining such trend behaviour, Rockguard provided enhancement which was seen to be nearly equivalent to the best response shown or intermediate between the other two types utilized. For similar tests conducted on the Quebec granodiorite rock, peak strength enhancement over a lower stress range was achieved, this shown to vary between 3.1 MPa/mm of lining (for RockWeb™) and 6.5 MPa/mm of lining (for Mineguard™). For the Quebec granodiorite, uniformly greater residual strength enhancement was noted to develop than for the Kingston granodiorite material, with an enhancement range existing between 2.1 MPa/mm of lining applied (for Rockguard™) and 3.5 MPa/mm of lining applied (for Mineguard™). Because of differences in the unconfined strengths of these two rock materials, similar levels of peak strength enhancement would not be anticipated. A lower degree of peak strength beneficiation was observed to develop for rock samples exhibiting lower measured unconfined strength behaviour. Under post-yield failure conditions, alternately, the application of passive liner agents, of all types, was shown to mobilize higher residual strength enhancement in rock materials exhibiting lower UCS, stiffness and deformation modulus character. Such dissimilarity in strength enhancement behaviour between different rock types may be influenced by individual rock characteristics. In fact, prior tests performed upon large scale concrete pillar models, ranging in size between 15 cm diameter by 30 to 100 cm in length, have indicated that, for weaker test specimens (UCS = 47.5 MPa), negligible peak strength and significant residual strength enhancement can be generated (Callery et al, 2000).

**Table 2. Conditions of strength and energy storage capacity enhancement versus lining thickness applied for Mineguard™, Rockguard™ and RockWeb™ lining materials**

**(a) Kingston granodiorite**

| Condition | Rockguard™ | Mineguard™ | RockWeb™ |
|---|---|---|---|
| **Peak Strength (MPa)** | Y = 179.7 + 4.6 X | **Y = 181.9 + 9.6 X** | **Y = 179.5 + 1.2 X** |
| **Residual Strength (MPa)** | Y = 2.8 + 2.0 X | **Y = 4.0 + 2.1 X** | **Y = 2.9 + 1.4 X** |
| **Post-yield Stored Strain Energy Capacity (J)** | Y = 41.8 + 9.4 X | **Y = 30.1 + 21.3 X** | **Y = 60.8 + 18.3 X** |

**(b) Quebec granodiorite**

| Condition | Rockguard™ | Mineguard™ | RockWeb™ |
|---|---|---|---|
| **Peak Strength (MPa)** | Y = 121.4 + 3.3 X | **Y = 123.5 + 6.5 X** | **Y = 121.7 + 3.1 X** |
| **Residual Strength (MPa)** | Y = 1.6 + 2.1 X | **Y = 0.1 + 3.5 X** | **Y = 3.3 + 2.7 X** |
| **Post-yield Stored Strain Energy Capacity (J)** | Y = 77.5 + 31.2 X | **Y = 16.8 + 66.3 X** | **Y = 109.7 + 43.3 X** |

The results of stored strain energy capacity versus lining thickness analyses, for both types of granodiorite rock tested, provided additional confirmation of the benefits of using all types of spray-on linings for rock reinforcement, though only in restricted regions of the "pillar" life cycle. For each lining applied, no significant energy capacity improvement was realized (see Figure 7) for either rock sample population within pre-yield portions of the loading cycle (ie.- where initial, elastic pillar loading takes place). In post-yield loading of samples of both rock types, very beneficial and positive strain energy storage trend behaviour was observed to result versus lining thickness applied. For the Kingston granodiorite, post-yield strain energy storage capacity enhancement was shown to range between 9.4 J/mm of lining thickness applied (for Rockguard™) to as much as 21.3 J/mm of lining thickness applied (for Mineguard™). RockWeb™ provided enhancement which was seen to be nearly equivalent to that of Mineguard™ for Kingston granodiorite tests. In further tests on the Quebec granodiorite cores, post-yield strain energy storage capacity enhancement was shown to vary between 31.2 J/mm of lining (for Rockguard™) and 66.3 J/mm of lining (for Mineguard™), with RockWeb™ response lying intermediate between these levels. Aswas the case for relative strength improvement noted to develop between Kingston and Quebec granodiorite rock materials, uniformly greater residual strain energy storage capacity enhancement was also generated for Quebec granodiorite, relative to Kingston granodiorite. When comparing strain energy storage capacity realized versus liner thickness applied for Quebec versus Kingston granodiorite materials, respectively, improved capacity enhancement ranged between approximately 200% for RockWeb™ and 300% for both the Rockguard™ and Mineguard™ liner materials. For Quebec granodiorite material, however, both the RockWeb™ and Mineguard™ lining materials provided better capacity, in terms of absolute energy potential, than Rockguard™ for enhancing strain energy storage capacity limits, with Mineguard™ providing optimal enhancement performance overall.

## CONCLUSIONS

A comprehensive examination of the failure behaviour of two dissimilar, but highly homogeneous, granodiorite rock populations has been completed. Such behaviour was observed for both populations when tested completely unconfined and following coating using different polymeric lining agents at varying thicknesses of application. The combination of data which is shown in Figures 6 and 7 provides justification that the entire range of polymeric spray-on liners used offers potential to improve the rock mechanical performance of core materials (used to simulate pillar structures) onto which they may be applied. Within this range of performance, individual polymers may yield better peak and/or residual strength enhancement than others, though all have been shown to provide some positive degree of support benefit relative to samples tested totally unconfined. In similar fashion, all liner materials have been shown capable of generating enhanced strain energy storage capacity within rock materials which, if uncoated, would experience violent failure and total loss of strain energy storage capacity otherwise.

For two rock materials, Kingston and Quebec granodiorites, strong and well-defined trends in strength improvement, both pre- and post-yield, were realized as the result of placement of three types of passive, spray-on polymer linings at thicknesses in the range between 1 and 7.3 mm. Variation in strength between the two types of materials was found to develop due to differences between the physical properties of each rock type and passive confinement conditions mobilized by the individual polymer agent materials used. For both Kingston and Quebec granodiorite materials, a range of capacities for enhancing peak pillar strength per unit lining thickness applied were demonstrated. For the limited core specimen sizes utilized, peak strength enhancement was observed to vary between 1.2 - 9.6 MPa/mm of lining thickness applied, with more uniform strength enhancement being developed upon the Quebec, rather than Kingston, granodiorite core materials and with Mineguard™, for both rock types, providing best strength improvement. When assessing residual strength improvement, all three polymer lining agents provided very similar advantage for strength enhancement within both rock sample populations. Residual strength gains ranging between 1.4 - 3.5 MPa/mm of lining thickness applied were observed, again with Mineguard™, for both rock types tested, providing best residual strength improvement overall. The results of stored strain energy capacity versus lining thickness analyses for the two rock types yielded additional confirmation of the benefits of using all three types of polymer spray-on materials for rock reinforcement. For all lining types, no significant energy capacity improvement was realized for most samples tested within the pre-yield loading state. In post-yield loading, however, beneficial strain energy storage capacity was developed when linings were applied to both populations of rock cores. For the limited core specimen sizes utilized, strain energy storage capacity enhancement was observed to vary between 9.4 - 66.3 J/mm of lining thickness applied, with higher overall capacity being developed for the Quebec, rather than Kingston, granodiorite core materials and when using the Mineguard™ polymer agent material.

The capacity to mobilize additional strength and generate corresponding increases in energy storage capabilities, beyond conditions achievable by totally unconfined rock specimens, has been shown to be a direct consequence of the application of passive polymeric linings onto rock "pillar" models. Such tests are currently of limited extent and indicative only of rock response under controlled laboratory failure conditions. In addition, performance tests exist solely for specimens and structural models which exhibit small scale, uniform size and geometrically-simple configurations. Research performed in this study, for two types of highly homogeneous rock and using a variety of polymer agents, has indicated that substantially positive strength and strain energy storage benefits can be derived from thin liner application. However, due to inherent variability in rock properties between individual specimens tested and to dissimilarity in polymeric coating material properties, some variation in enhancement response was also noted to develop. Variability in rock character is difficult to mitigate, though change in polymer physical characteristics through engineering alterations in lining strength, surface adhesion properties, elongation characteristics and the like can be achieved. Such properties, though variable, have been shown to be positive for providing potential benefit for rock reinforcement.

Existing tests have examined only a limited number of potential spray-on coating agents which are currently and commercially available. Such research will also benefit by broadening the search and review of additional forms of polymeric coatings. Eventual validation of this support technique and its benefits can, however, only be realized by expanding the research scope into full scale field installation trials.

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